Changes in Frequency of Extreme Wind Events in the Arctic

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LONG-TERM GOALS

The primary objective of the research was to synthesize output from state-of-the-art climate models in order to provide projections of 21st-century changes in Arctic sea ice, wind and other variables that affect marine operations in the Arctic. The scenarios of sea ice coverage and storm events obtained here can ultimately be used in downscaling applications relevant to high-wave events, vessel-icing conditions and ocean mixing. Changes in these conditions will have impacts on military operations, commercial activity, and marine organisms in the Arctic.

OBJECTIVES

The specific objectives of the project were to (1) document changes of Arctic cyclone activity over the past 50-55 years, with an emphasis on the extreme events, (2) evaluate and optimize the 21st-century projections of sea ice by synthesizing output from greenhouse simulations by global climate models, and (3) combine the projections of sea ice with the projected changes of cyclone activity and air temperature to obtain scenarios of change of high-wave events and vessel icing. In order to achieve objectives (2) and (3), it is necessary to use observational data on sea ice coverage to adjust for biases in the models' simulated sea ice cover, thereby altering the timing of the reduction of sea ice cover in the Arctic. Finally, the substantial across-model variance of the present-day and projected climates leads to a fourth objective, which is to use the across-model variance to quantify the uncertainties in the 21st-century projections.

APPROACH

The approach is based on a combination of data analysis and a synthesis of model projections of climate change through 2100. The data analysis consisted of a documentation of cyclone activity over the past 54 years, with en eye toward low-frequency variations and trends of (a) Arctic cyclones in general and (b) extreme events. The latter include the cyclonic systems with the lowest central pressure and/or the strongest pressure gradients. Since the wind speeds are proportional to pressure gradients, the strongest pressure gradients will generally correspond to the strongest wind events. If these events occur over ice-free waters, the potential for high-waves and coastal flooding/erosion is maximized. In addition, if such events occur when the air temperature is below freezing, severe vessel icing can occur.

The project's second component was a synthesis of the output from a suite of global coupled climate models run under a scenario of increasing greenhouse gas concentrations. The five models, which are the same as those being used in the Arctic Climate Impact Assessment, are those of the Canadian Climate Center, the Max-Planck-Institute in Germany, the Geophysical Fluid Dynamics Laboratory in the U.S., the Hadley Centre in the U.K., and the National Center for Atmospheric Research (CSM model) in the U.S. The greenhouse simulations by these models were forced by the "middle-of-the-road" B2 scenario of the Intergovernmental Panel on Climate Change. The required information on sea ice and its changes has been evaluated from monthly fields (observed and projected), while the information on storm (wind) and temperature events has been based on daily summary fields. Four of the five models have provided archives of daily winds from a B2 scenario simulation extending through 2100; all five models have provided monthly fields for evaluations of projected changes in mean winds and temperatures.

WORK COMPLETED

As the project nears its completion, we have completed work on the first two specific objectives, nearly completed work on the third specific objective, and quantified the across-model variance noted above as the fourth specific objective. Specifically, the following tasks have been completed:

1. A website depicting current and recent Arctic sea ice coverage and departures from normal (on an Arctic-wide and a regional basis) has been constructed and is now accessible at http://zubov.atmos.uiuc.edu/CT.

2. 21st century sea ice projections from the five global climate models have been evaluated and synthesized in a study directed at navigability of the Arctic Ocean. The results have recently been published (Walsh and Timlin, 2003).

3. Arctic storm statistics for the past 50 years, as well as the relationship between Arctic storm variability and the large-scale circulation, have been evaluated from NCEP reanalysis data. The results have been submitted for publication (Zhang et al., 2003).

4. Variations of the most intense Arctic cyclones and anticyclones over the past 55 years have been evaluated on a decadal basis in order to document secular variations of intense Arctic cyclone activity.

5. The synthesis of information on strong-storm events in a framework of decreasing sea ice coverage and air temperature variations has been initiated in order to address the variations of high-wave events and vessel icing conditions.

RESULTS

The evaluation of the global climate model projections of Arctic sea ice through the 21st century included an enhancement of the informational content through an adjustment of each model's projection based on a correction for systematic errors. These adjustments were derived from the regionally and seasonally varying biases of each model's sea ice coverage relative to the HadISST sea ice dataset. All five models show decreases of ice extent ranging from about 12% to 46% (Walsh and Timlin, 2003, their Fig. 4 and Table 1). The mean decrease is approximately 30%, although the percentage decrease is larger in summer than in winter. The decrease observed over the past several

decades is also larger in summer than in winter. Only one model (the Canadian model) is consistently ice-free during the summer months by the late 21st century, although it must be noted that the B2 scenario of greenhouse gas forcing results in less warming than the other commonly used scenario, A2. The results have been extended to include a quantitative evaluation of the 21st-century evolution of the length of the navigation season in the Northern Sea Route (Figure 1). For a wide range of navigability criteria, the length of the navigation season is projected to increase by 2-4 months by the end of the 21st century.

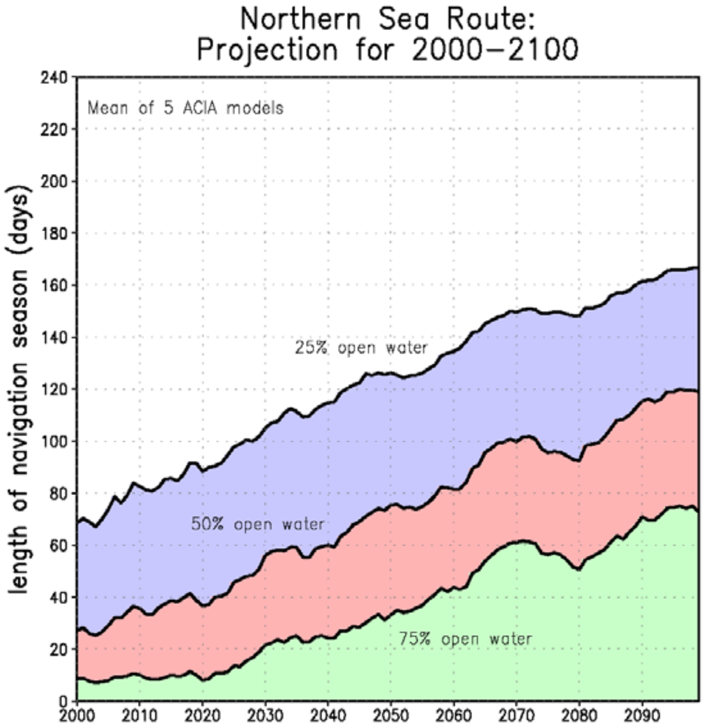

Figure 1. A composite projection based on the five global climate models indicates that the navigation season length in the Northern Sea Route will increase from about 10 days to 75 days if 75% open water is required along the entire route, from about 30 days to 110 days if 50% open water is required, and from about 70 to 165 days if only 25% open water is required along the entire route.

The evaluation of extreme cyclone events has been performed for several domains, including the Arctic Ocean and the northern Alaskan region. An outstanding feature of the results is that the most intense cyclones have occurred preferentially in the more recent decades. Figure 2, for example, shows the 11-year (~decadal) distributions of the twenty-five most intense high- and low-pressure systems of the 1948-2003 period. While the high pressure systems show little secular variation through the period (easing concern about temporal changes in the observing network), there has been a systematic increase in the number of intense low pressure systems. This increase is apparent in all seasons, but is most apparent in summer (Jun-Aug) -- the season of greatest sea ice retreat, both observed and projected. While many of the most intense winter systems have occurred on the Atlantic side of the Arctic, the spatial distributions for the summer months (e.g., August) are rather homogeneous over the Arctic Ocean.

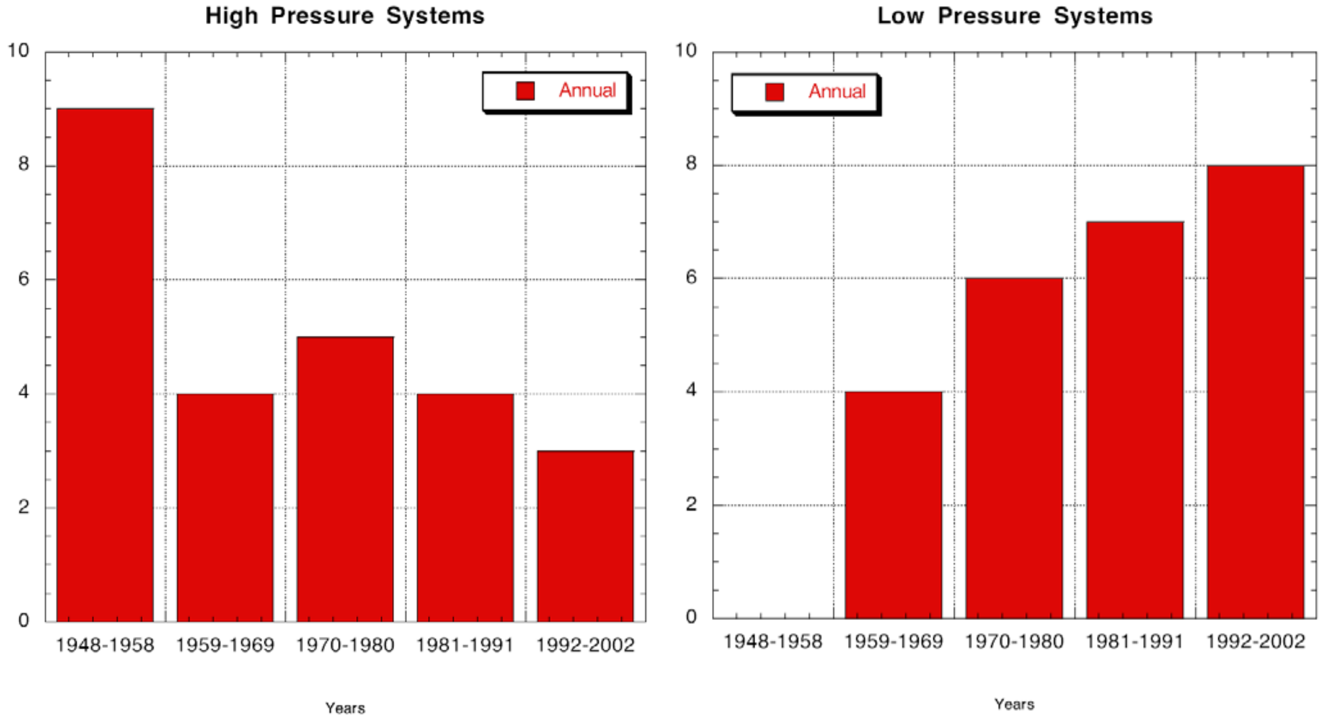

Figure 2. The decadal distribution of the most intense (a) high and (b) low pressure centers over the Arctic Ocean during 1948-2002 shows no systematic increase of intense high centers, but a systematic increase of intense low centers.

In a recently completed diagnostic study (Zhang et al., 2003), we have placed the variations of Arctic cyclone activity into a context of large-scale low-frequency variability in the Northern Hemisphere. This study utilized an Arctic Cyclone Activity Index (CAI)", which integrates information on variations of cyclone frequency, intensity and duration. The CAI analysis showed that Arctic cyclone activity indeed increased during the second half of the 20th century, in agreement with the findings about the most intense cyclones described in the preceding paragraph. The analysis also showed that midlatitude cyclone activity generally decreased over the same period, suggesting that a shift of storm tracks underlies the changes. Additional findings in this study are that (1) the Eurasian sector makes the largest contribution to the midlatitude variations, and (2) low-frequency variations are superimposed on the secular variations of Arctic cyclones. Prominent among the low-frequency variations is a 7-8 year oscillation that is consistent with the alternation of cyclonic and anticyclonic regimes of Arctic sea ice and ocean motions as documented in the literature by Proshutinsky, Johnson and others.

Finally, the work on trends of Arctic cyclones has been integrated with a documentation of recent variations of Arctic sea ice coverage. As shown at the project's related website (http://zubov.atmos.uiuc.edu/CT), new 20th-century records for minimum sea ice have been achieved on several occasions during the past 15 years. The combination of reduced summer ice extent and increased incidence of summer cyclones, especially intense cyclones, is consistent with the increase of coastal flooding and coastal erosion in the Arctic. We are now experimenting with the synthesis of data on storm intensity (as measured by the maximum pressure gradient) and open-water fetch in order to obtain quantitative estimates of increases of wave activity in the Arctic during summer and autumn.

Air temperature is being added to this evaluation in order that changes in vessel icing conditions may also be addressed.

IMPACT/APPLICATIONS

The project has produced state-of-the-art projections of future Arctic sea ice coverage, utilizing the output from a suite of the most highly regarded global climate models (as indicated by their selection for use in the Arctic Climate Impact Assessment). The 30% decrease of the annual mean ice coverage (42% in summer, 18% in winter) has profound implications for surface marine operations -- military, commercial and tourism-driven) in the Arctic. In particular, military operations presently influenced by summer/autumn sea ice in the Alaskan sector and in the Russian sector may be significantly impacted. Since the best estimates are that the largest sea ice changes are decades away, a window for planning and adaptation is available. The increase of storminess during the summer season complicates the planning process, since increased surface navigation will be susceptible to enhanced storminess and wave activity during the summer, as well as increasing incidences of potential icing conditions during autumn. Finally, the across-model variance of the projected changes can enable the planning process to include measures of uncertainty in the future scenarios.

TRANSITIONS

A website depicting current (updated daily) and regional sea ice coverage is now accessible at http://zubov.atmos.uiuc.edu/CT. This site also provides context for the present sea ice anomalies by showing their evolution over the past year, on an Arctic-wide and a regional basis. This website is presently accessed by more than 200 users on a typical day. It has also been filmed for inclusion in a PBS production on Arctic climate change, scheduled for next January on *Scientific American Frontiers*. Finally, the results have been incorporated into the Arctic Climate Impact Assessment (see below).

RELATED PRODUCTS

The P.I. (Walsh) is the lead author of Chapter 5 (Cryospheric and Hydrologic Variability) of the Arctic Climate Impact Assessment [http://www.acia.uaf.edu]. Walsh has incorporated some results from this project into the chapter's section on sea ice, specifically the material on recent variations, projected changes, and likely impacts. (The presentation of this material has been coordinated with the authors of ACIA Chapter 15, which addresses impacts on infrastructure in the Arctic). The sea ice section of Chapter 5 is complemented by other sections (ice sheets and glaciers, snow cover, permafrost, river and lake ice, hydrologic fluxes) prepared by contributing authors. The ACIA report is now undergoing scientific review; publication of the final ACIA report is scheduled for September 2004.

PUBLICATIONS

Walsh, J. E., and M. S. Timlin, 2003: Northern Hemisphere sea ice simulations by global climate models. *Polar Research, 22),* 75-82 [published, refereed].

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